Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Natural Resources and
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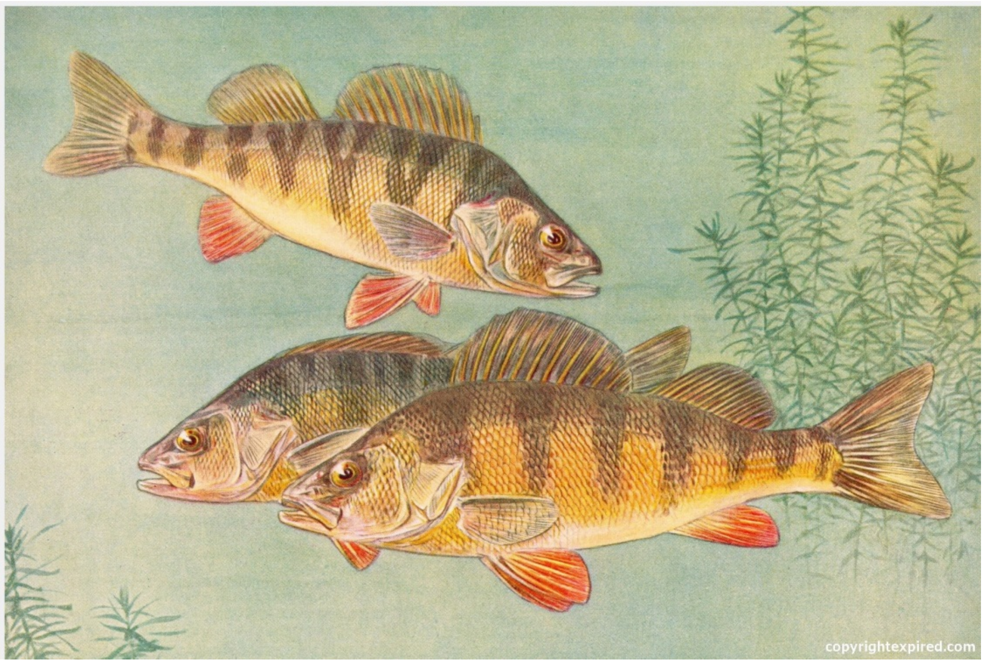
Assessing the importance of freshwater tributary systems for the recruitment of Eurasian Perch (*Perca fluviatilis*) in Baltic Sea Coastal Ecosystems

Joe Wastie



Department of Aquatic Resources
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Assessing the importance of freshwater tributary systems for the recruitment of Eurasian Perch (Perca fluviatilis) in Baltic Sea Coastal Ecosystems in English

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ABSTRACT

Populations of one of the most important predatory fish species within Baltic Sea coastal ecosystems, the Eurasian Perch (*Perca fluviatilis*), have declined in some coastal areas during recent decades. This has caused negative effects on an ecological, commercial, and cultural scale, and protection and restoration of recruitment areas (perch spawning grounds) are believed to be an important player in supporting future stocks.

Freshwater systems close to coastal areas have previously been noted as important spawning grounds for other fish species resident in coastal areas, but relatively little is known of this for perch. In this study, the main aim was to assess the importance of freshwater systems for the recruitment of coastal perch along the Swedish Baltic Sea coast, using otolith micro-chemistry. Otoliths were removed from perch specimens and analysed for strontium (Sr) and calcium (Ca) ratios via particle induced x-ray emissions techniques (μPIXE). In order to determine birth origin of the coastal perch in the study areas, a freshwater baseline was established using other freshwater recruited coastal perch, as well as lake perch specimens.

The results showed that the majority of perch juveniles in coastal areas were recruited in brackish water, albeit with variation across areas. In one area however, freshwater systems appeared to be extremely important for perch recruitment in the coastal area.
Notable changes in habitat between resident maternal environment, and juvenile birth environment were also assessed (via changes in salinity) to speculate maternal spawning preferences. This study showed that on average 30 % of juvenile fish caught in coastal areas had a ‘pronounced dip’ in their Sr:Ca profiles, which suggests that adult perch migration into waters with notably lower salinity for spawning is not uncommon in the Baltic Sea.
Often otolith strontium concentrations are suggested to be positively correlated to the respective salinity found in the resident habitat of a fish. This study found no correlation, and no apparent trends linking ambient salinity and Sr:Ca ratios in otolith cores.

In order to restore and maintain future perch stocks in the Baltic Sea it seems that the most important habitats to protect are those in the coastal areas, but freshwater systems in some areas must also be considered. Once these important recruitment sites are identified, both land and water management measures should be employed in order to conserve these sensitive coastal ecosystems, or return them to a natural state.

CONTENTS

INTRODUCTION

The Baltic Sea is one of the largest brackish water bodies in the world. Due to relatively low salinities, the respective fish community in some coastal areas is comprised of both marine and freshwater species (Nilsson et al., 2004; Olsson et al., 2012). Fish often play a key role in aquatic ecosystem functioning via top down control (Eriksson et al., 2009) and one of the most important predatory fish species within Baltic Sea coastal ecosystems is the Eurasian Perch (*Perca fluviatilis*).

Weakened predator populations of larger fish such as perch and the northern pike (*Esox lucius*) in some Baltic sea coastal ecosystems may have generated strong increases in smaller sized predatory fish, a phenomenon known as meso-predator release (Jackson et al., 2001). In the Baltic Sea, this release in predation pressure may be a contributing factor to explain a notable population boom of three-spined sticklebacks (*Gasterosteus aculeatus*) in certain areas (Nilsson, 2006; Ljungren et al., 2010). The resulting impact of such exponential stickleback population growth may have severe consequences for perch during their early life stages. These early larval and juvenile life stages are believed to be very sensitive, and can result in large variations regarding annual recruitment success (Juanes, 2007). The knock on effects to lower trophic levels (caused by excessive stickleback populations) also shows a reduced number of floral grazing organisms such as amphipods and gastropods, which can promote the growth and formation of macro-algal blooms (Sieben et al., 2010). Algal overgrowth can damage fish spawning grounds (Aneer, 1987), often due to a lack of oxygen in the surrounding water. The coastal ecosystem at this point often experiences a loss in biodiversity as a result of the eutrophic symptoms, and hence highlighting the ecological significance of predatory fish in coastal areas.

Perch also have a commercial value, and are a common target species of the small-scaled coastal fishery. On a larger scale, trends in popularity of perch as a ‘food fish’ have been mirrored by a growth in the aquaculture market throughout Europe in recent years (Irish Seas Fisheries Board, 2008). The social value of the species is also notable, as it is often a choice fish amongst sport fisherman and the less experienced angler alike. As such, the importance of perch can be understood from several perspectives. Any changes that occur within coastal ecosystem functioning could damage the structure within that system, and result in a profound loss of ecological, cultural and economical values which we want to protect.

It is therefore a great concern that in recent decades, data from some coastal regions in the Baltic Sea has indicated notable stock declines of the two most dominant coastal predatory fish species; perch and the northern pike (Nilsson et al., 2004; Ådjers et al., 2006; Ljunggren et al., 2010). The rarity of perch and pike in catches was particularly highlighted during the early 1990’s by commercial and recreational fisherman in the Kalmar Sound area of Sweden, and investigations began to take place to try and identify possible causes. Weak recruitment of juvenile fish was argued to be a significant factor in explaining the declines of both perch and pike in some of the affected coastal areas (Nilsson et al., 2004; Lehtonen, et al., 2009; Ljungren et al., 2010).
A number of different factors may contribute to weakened perch recruitment. These may include eutrophication affecting spawning grounds (Sandström and Karås, 2002), cannibalism or intraspecific competition by larger perch (Persson et al., 2000, 2004), food resource competiton with other fish species such as sticklebacks (Olsson et al., 2012) or specialised offshore planktivores such as sprat (*Sprattus sprattus;* Ljungren et al., 2010), and predation during early life stages by pike (Treasurer et al., 1991), three-spined sticklebacks (Olsson et

al., unpublished), and to a lesser extent the common roach (*Rutilus rutilus*; Persson and Greenberg, 1990). Another key element is the exploitation and degradation of spawning grounds. In some coastal areas of the Baltic Sea, suitable spawning habitats are estimated to explain almost half of the variation in population size of perch (Sundblad et al., 2013). Hence fish recruitment processes are shown to be very sensitive and even small changes in the environment, or ecosystem dynamics, may produce large variations in the reproductive success of a certain species (Hjort, 1914).

As with other freshwater fish species that inhabit coastal regions in the Baltic Sea, perch may also migrate into freshwater systems during the spring to spawn (Muller and Berg, 1982). This strategy is explained as a means of finding and utilising alternative spawning and nursery habitats, that may be more profitable for the offspring (Urho et al.,1990). Optimal spawning grounds that perch seek are found in shallow, warm waters where they can find stable objects such as submerged branches or vegetation on which to attach their egg strands (Sundblad et al., 2011).

Migratory patterns from brackish water to freshwater spawning grounds have in fact been well documented in other Baltic Sea fish species such as sea trout (*Salmo trutta*; Limburg et al., 2001) and pike (Lehonen and Hudd, 1990; Urho et al.,1990; Westin and Limburg, 2002). These journeys also appear to be profitable, returning a significant proportion (45 %) of pike recruits to some coastal areas of the Baltic Sea (Engstedt et al., 2010), although there is substantial variation across areas.
It is therefore very plausible that freshwater systems such as rivers, brooks and wetlands within close proximity to the Baltic Sea coastline may be of great value to perch recruits as well. These sites could be of key importance in managing future perch populations, so identifying and protecting certain spawning grounds may help to strengthen the stocks of coastal perch in the Baltic Sea.

One method by which the natal origin of fish can be assessed is using otolith micro-chemistry. This has proven to be especially useful for assessing whether a fish is recruited in freshwater or brackish water (Campana, 1999). Otoliths are bone-like structures found within the head of fish, and consist mostly of calcium carbonate. Their practical function is to assist with hearing, balance and orientation systems in all teleost fish (Campana, 1999). When a fish grows, the otolith grows with it, and continually encorporates chemical elements from the surrounding water into the otolith throughout the fish's lifespan. Thus, an otolith could be described as a chronological timekeeper of the water in which a fish has resided (Elsdon et al., 2008) and of particular interest is the relative concentrations of the elements strontium (Sr) and calcium (Ca) found within the otolith. This is because the ratio of Sr:Ca in water is generally positively correlated to salinity (Zimmermann, 2005), with lower Sr:Ca values generally suggesting freshwater residency, and higher values tending to imply marine or brackish residency (Engstedt et al., 2012).

In this study, otolith micro-chemistry was used to address the following objectives:
(i) Establish a Sr:Ca freshwater baseline value using coastal perch specimens recruited in a freshwater river, as well as fish from six freshwater lakes. (ii) Using the established freshwater baseline, assess the natal origin of perch from six different coastal areas along the Swedish Baltic Sea coast and assess the share of freshwater recruits from each area. (iii) Analyse Sr:Ca profiles in each fish to assess any abrupt changes in habitat use during the first weeks of life, and, (iv) Discuss potential explanations for differences in the share of freshwater recruitment at different coastal areas.

MATERIALS AND METHODS

Study areas and collection of samples:

A total of 226 perch otoliths were analysed for this report. 28 of these perch were caught in late August 2011 from the River Sävarån at Skeppsvik (63°47′57N 20°34′41E), close to the city of Umeå (fig.1). These fish served as the reference perch to establish the freshwater baseline value. Small underwater detonations (described by Snickars et al., 2007) were used to collect these fish.

To improve accuracy when establishing the freshwater baseline, 37 perch caught from six lakes were also included (fig.1). These were caught using Nordic type multi-mesh gill nets (30m x 1.8m deep), set for a time period of 12 hours (Swedish Standard Institute, 2006). The lakes were mainly located in southern Sweden but were widely dispersed geographically. Lake perch specimens used for analysis were caught in the summers of 2003 and 2010 respectively (table 1). Birth years of the lake fish were variable (between 1999-2007) and therefore fish were either 3 or 4 years old, but two specimens from Kånkåstjärnen were 5 and 7 years old.

Table 1: Site specifics of the freshwater lakes (grid reference system used is WGS84)

Freshwater Lake	Grid Ref: LAT	Grid Ref: LON	No. of fish	Birth year	Collection year	Length range of fish (mm)	Mean length of fish (mm)
Kånkåstjärnen	62°36'25.2"N	16°53'51.9"E	2	2003/2005	2010	196-226	211
Motjärn	59°18'12.4"N	12°10'43.3"E	2	2007	2010	168-176	172
Geten	58°33'15.4"N	15°43'13.5"E	4	2007	2010	119-142	127
Stengårdshultasjön	57°32'29.1"N	13°49'10.6"E	2	2007	2010	136-144	140
Gyltigesjön	56°45'30.1"N	13°10'34.7"E	6	1999	2003	107-133	121
Stora Skärsjön	56°40'28.3"N	13°4'16.2"E	21	1999/2007	2003/2010	122-162	137

The remaining 161 perch samples were caught from six different Baltic Sea coastal sites along the Swedish east coast, from Holmön, in the north of Sweden, down to Torhamn, in the south (fig.1). The fish were obtained from coastal monitoring programmes in August 2010 (described by Söderberg, 2008) using Nordic coastal multi-mesh gill nets (45m x 1.8m deep).

Between 21 and 30 perch were used for analysis from each coastal area (table 2). All fish were 3 years old, apart from the fish from Forsmark which were only 2 years old, but never the less, all individuals were born in 2007. The length ranges of the fish also varied between areas but all specimens were between 137-281 mm.

Table 2: Site specifics of the six coastal sites

Coastal site	Grid Ref: LAT	Grid Ref: LON	Relative Salinity ‰	No. of fish	Birth year	Collection year	Length range of fish (mm)	Mean length of fish (mm)
Holmön	63°40'38.7"N	20°52'0.5"E	3.5	29	2007	2010	168-237	196
Gaviksfjärden	62°51'57.6"N	18°15'2.5"E	4.5	28	2007	2010	138-242	202
Långvindsfjärden	61°27'49.0"N	17°9'40.0"E	4.8	30	2007	2010	137-230	179
Forsmark	60°30'13.5"N	18°7'54.9"E	4.6	21	2007	2009	153-234	184
Kvädöfjärden	58°0'17.4"N	16°44'18.7"E	6.3	28	2007	2010	162-251	195
Torhamn	56°5'4.3"N	15°47'37.6"E	6.9	25	2007	2010	216-281	254

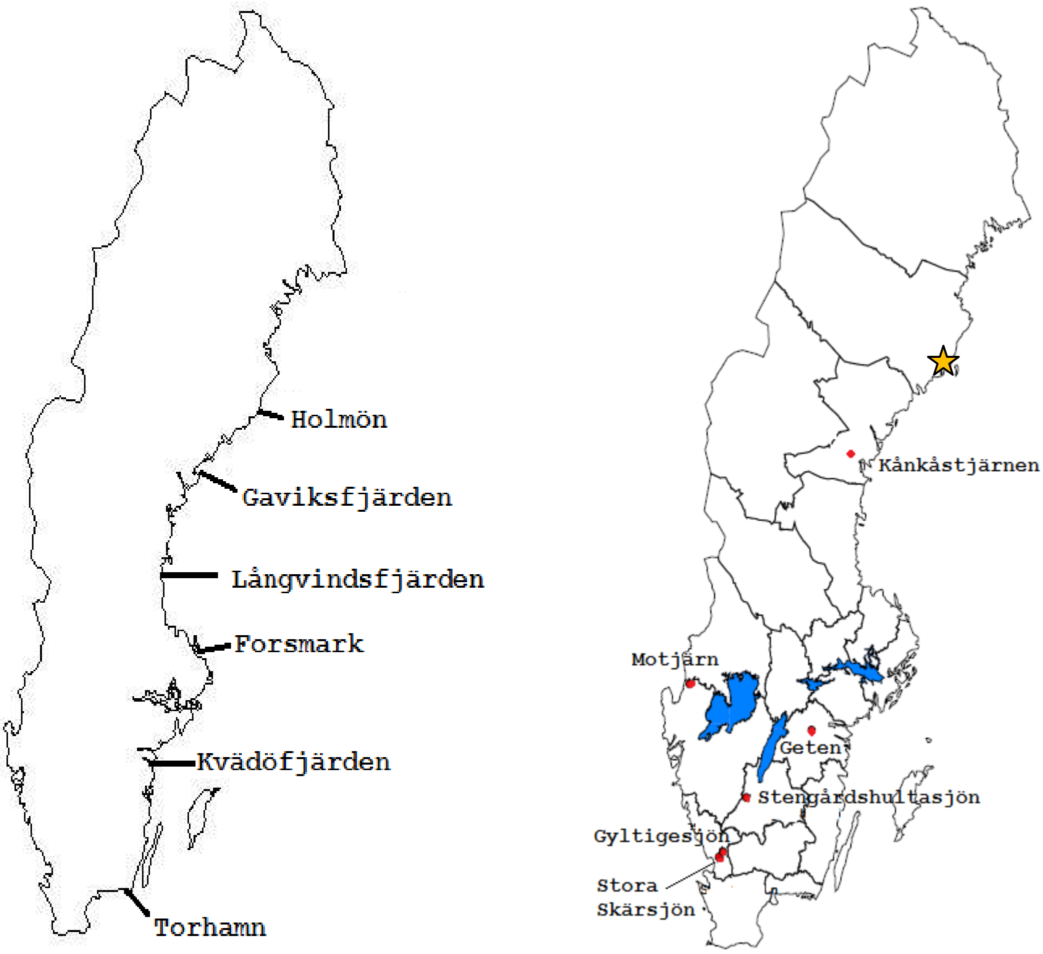

Fig. 1: Maps of Sweden displaying site locations of the six coastal areas along the Baltic Sea east coast (left) and the six freshwater lakes which are named (right). The River Sävarån is shown by the star (right).

Description of coastal areas:

The six coastal sites are national and/or regional reference areas within the Swedish Coastal Monitoring Programme.

Holmön

The most northernly coastal area is situated within the Holmön islands nature reserve, and has further protection through its status as a Natura 2000 site. The island location is roughly 10 km east of the mainland, and is somewhat isolated by a 40 m deep channel running between the two. Water depths in the study area are however much shallower, typically between 3-6 m. The isolation of the island group means that freshwater influences are very limited or not present at all, although salinity has decreased over the last ten years (Söderberg, 2013).

Perch and roach dominate the coastal fish community in the area, and coastal gill-net monitoring has shown that they currently account for approximately 90 % of the biomass within the fish community. This does however appear to be changing and indications show a fish community reduction in predatory fish species such as perch, shifting towards a carp-family (cyprinidae) domination state with increased catches of roach and bleak (*Alburnus alburnus*) between 1989-2012 (Söderberg, 2013).

Gaviksfjärden
Gaviksfjärden is within close proximity of a Natura 2000 site, and is largely unaffected by industry or human activites. Water quality is good, and water clarity has remained relatively stable at around 5 m secchi depth for the past ten years (Lingman, 2013). Freshwater tributaries are fairly abundant at this site, and offer a plentiful alternative to resident coastal perch for spawning purposes. Such examples can be found at Ramsta in the south, or at Gavik in the west. In addition to these, a network of streams draining many small freshwater lakes can be found around Nordingrå to the north.
The fish community has seen a dramatic population explosion in the numbers of three-spined sticklebacks in recent years, with catch per unit effort (CPUE) values increasing from an average of 2 sticklebacks per net and night in 2004, up to an average of 199 individuals per net per night in 2010 (Lingman, 2013). No other coastal site comes into close proximity of this figure which correlates to 8 sticklebacks for every perch individual. The Baltic herring (*Clupea harengus*) has also increased in numbers during the same time period. Perch populations have however remained stable, and still represent 99% biomass of predatory fish in monitoring catches in the area, even if pike, burbot (*Lota lota*) and lesser pipefish (*Syngnathus rostellatus*) are included (Lingman, 2013).

Långvindsfjärden
Långvindsfjärden is characterised by a substantial water exchange with the open sea, low influx of freshwater or nutrient supply, and industrial effluent is proportionally low compared to neighbouring coastal areas (SLU, 2013). Water clarity is good, suggesting very low biological production throughout the water column. Average depths are around 8m with a maximum depth of 33 m (SLU, 2013). Freshwater systems can be found in the area, in the form of small stream networks that drain lakes (Andtjärn) and nearby marshland (around Kallviken and Årsviken). A notable freshwater source is the drainage of the lakes Hålldammen and Aldersjön via a river system which enters the sea at Långvinds Harbour.
The fish community is strongly dominated by freshwater species such as perch and roach, however three-spined stickleback populations have increased notably during recent years. The increase in sticklebacks is from just a few individuals during the first eight years of monitoring, up to an average of eight individuals per net and night from recent years (2010-2012). Fish diversity has increased in catches over recent years, and can partly be explained by a reduced dominance of perch and roach which represented 89 % of the biomass of the coastal gill net catches in 2002, but just 45 % in 2012 (SLU, 2013).

Forsmark
This area has been well monitored since the late 1970's as part of the environmental surveillance program for the Forsmark nuclear power plant. Large parts of the northern and central area are quite wave exposed, with the southern area more sheltered. Maximum water depths are between 6-10 m, but around 40 % of the area is however shallower than 3 m (SLU, 2013). Small islands and skerries are common, with much of the area also protected as a Natura 2000 site. Freshwater influences are notable in the area and are mostly in the form of small streams draining wetland areas and small lakes. These can be found close to the areas of Rundskär, Skaten, and Stor-rångsen. Further examples can be found in several locations surrounding Forsmark power plant such as close to Bergöarna and Bolundsfjärden lake system. In the south , the large freshwater lakes Norra Åsjön, Södra Åsjön and Bruksdammen are drained via the river Forsmarksån into the sea.
The dominant fish species found are perch, roach and white bream (*Abramis bjoerkna*), although the ratio of these varies greatly between different years. In 2002 for example, there

were five times more perch caught in comparison to cyprinid fish (such as roach), than were caught just two years later in 2004. Perch recruits have however been declining notably in the area during the most recent years (SLU, 2013).

Kvädöfjärden

This coastal area has been a national reference site since 1988. Water clarity has decreased and temperature increased in the area, since earlier monitoring started in the middle of the 1960's however. The inner parts of the archipelago are sheltered and quite shallow with an average depth of around 5 m, whereas the outer regions are much more wave exposed and can be as deep as 25 m (Söderberg, 2013). Large parts of the area fall within the Torrö and Åsvikelandets nature reserves, and are therefore well isolated from the negative effects of boating, agriculture or waste outlets. Freshwater influences are present but very limited, with examples including a few small streams to the north and north-west, for example at Hökdalen and Bäcksviken. Alternative freshwater sources can be found just outside of the monitoring area, for example due west close to Kaggebo.

The fish community is dominated by perch and roach, however some cyprinid species such as roach and rudd (*Scardinius erythrophthalmus*) have declined significantly over time whilst the abundance of marine species such as Baltic herring and flounder (*Platicthys flesus*) have increased (Söderberg, 2013).

Torhamn

Torhamn is the most southerly area, and salinity found here is almost double of that recorded at Holmön. The area is shallow (3-6 m) and protected from the open sea by a large archipelago containing many small islands. Large rivers or brooks are not present within the survey area, but very limited freshwater courses can be found to the north (Söderberg, 2013).

Perch and roach once again dominate the fish community (ca. 90 % of the total fish biomass) but pike are also representable in the area. Perch grow fast here, and account for 96 % of the biomass of the coastal predatory fish, with an average CPUE value of twenty fish caught per net per night between 2002-2012 (Söderberg, 2013).

Preparation of otoliths:

For otolith chemistry to be performed, the largest pair of otoliths known as the saggitae were removed and prepared for analysis by laboratory personnel at the Institute for Coastal Research, Öregrund, Sweden.

Otoliths were first extracted using a knife or scalpel, then rinsed with alcohol and dried thoroughly before being stored in eppendorf tubes with identification numbers.

After this the otoliths were embedded individually in epoxy resin (Struers Epofix resin) and were carefully ground sulcus side down against a grinder (using grit) to expose the otolith core.

Once the otolith core was visible, polishing could then be performed firstly using 3 M lapping film and then finished off using 1 M Liquid diamond solution (Kemet).

The otoliths were finally mounted onto a glass slide with LocTite quick glue made for glass adhesion, cleaned with ethanol, and labelled with individual fish ID codes prior to chemical composition analysis (fig. 2).

Fig. 2: Perch otoliths were extracted, cleaned, ground down and polished, then attached to glass slides. Photos: Yvette Heimbrand

Micro-chemical analysis of otoliths:

In order for the study objectives to be answered, all otoliths were analysed for their respective concentrations of Sr and Ca (amongst other chemicals) at the Nuclear Microprobe Laboratory in Lund. The technique used was Particle-Induced X-ray Emission spectrometry (μPIXE). This method was chosen as it allows for a whole multitude of major and trace elements to be detected (Johansson and Johansson, 1976) which may have been grafted into the otolith from the surrounding water in which a perch inhabits.

The process works by shooting a proton beam of 2.55 MeV and beam current of around 10 nA over the surface of the otolith (Engstedt et al., 2010). The beam is able to detect specific chemical compositions along a 512 point transect, recording the chemical composition every 6 μm across the otolith from one edge to the other. It is however imperative that the proton beam runs directly through the otolith core; this being established by a provisional 'mapping scan' testing purely for strontium (fig. 3).

Treatment and analysis of data:

When treating the data the first detail to establish was the location of the otolith core. The μPIXE scan images (fig. 3) provided the first guideline to help with this. Often the core region was quite apparent, a result of the proton beam detecting higher Sr concentrations which are shown by a deeper, more saturated colouration (fig. 3).
In around a dozen cases however, the core region was not so obvious and other dark spots were present which could be misinterpreted as the otolith core. These 'false cores' were likely to be either dust or dirt, or another (unexplained) concentrated patch of strontium. In this situation the normal growth pattern of an otolith was considered, which is from the centre outwards- similar to that of a tree ring growth. Hence it was often possible to follow a path into the centre of the image using the otolith growth rings as an inwards funnel to the core.
If any doubt remained, individual otolith photographs taken during the preparation stage were consulted and compared with the μPIXE scan images to help find the core. Thus accuracy associated with the core identification process was deemed to be high.

Fig. 3: Locating the otolith core - μPIXE strontium mapping scan showing the core from a fish at Långvindsfjärden (left) The similarity with tree growth rings as a guide into the core region (centre) and a photographed otolith, ground and polished before micro-chemical analysis (right). (Photo: Yvette Heimbrand)

Once the core had been identified, the evaluation software package 'GeoPIXE' was used to transform the specific pixel site of the core (from the μPIXE scan image) to one of 512 transect points in an accompanying Excel file. This meant it was possible to overview specific Sr and Ca concentrations found at a specific pixel site, and allowed further evaluation as to whether the core was in fact accurately located or not.

If satisfactory, the highest Sr concentration in the core region was defined as the core, a result of 'mother peaks' found in otoliths (described later). Neighbouring transect points with higher Sr values than those suggested by the scan image may therefore have been selected to represent the otolith core. A profiled line plot could then be constructed to show the variation in Sr and Ca concentrations throughout the whole transect (fig. 4).

Since information detailing life history is effectively mirrored on both sides of the core, it was also necessary to decide exactly which portion (roughly one half) of the otolith was most suitable to extract data from. Two issues were taken into account (i) which side contained the largest amount of information, and, (ii) was the Ca concentration stable in that portion.

Calcium levels should not fluctuate in the otolith because its uptake and deposition in the otolith is not associated with ambient salinity. Hence a straight Ca line is optimal (fig. 4) and should be expected from accurately processed data.

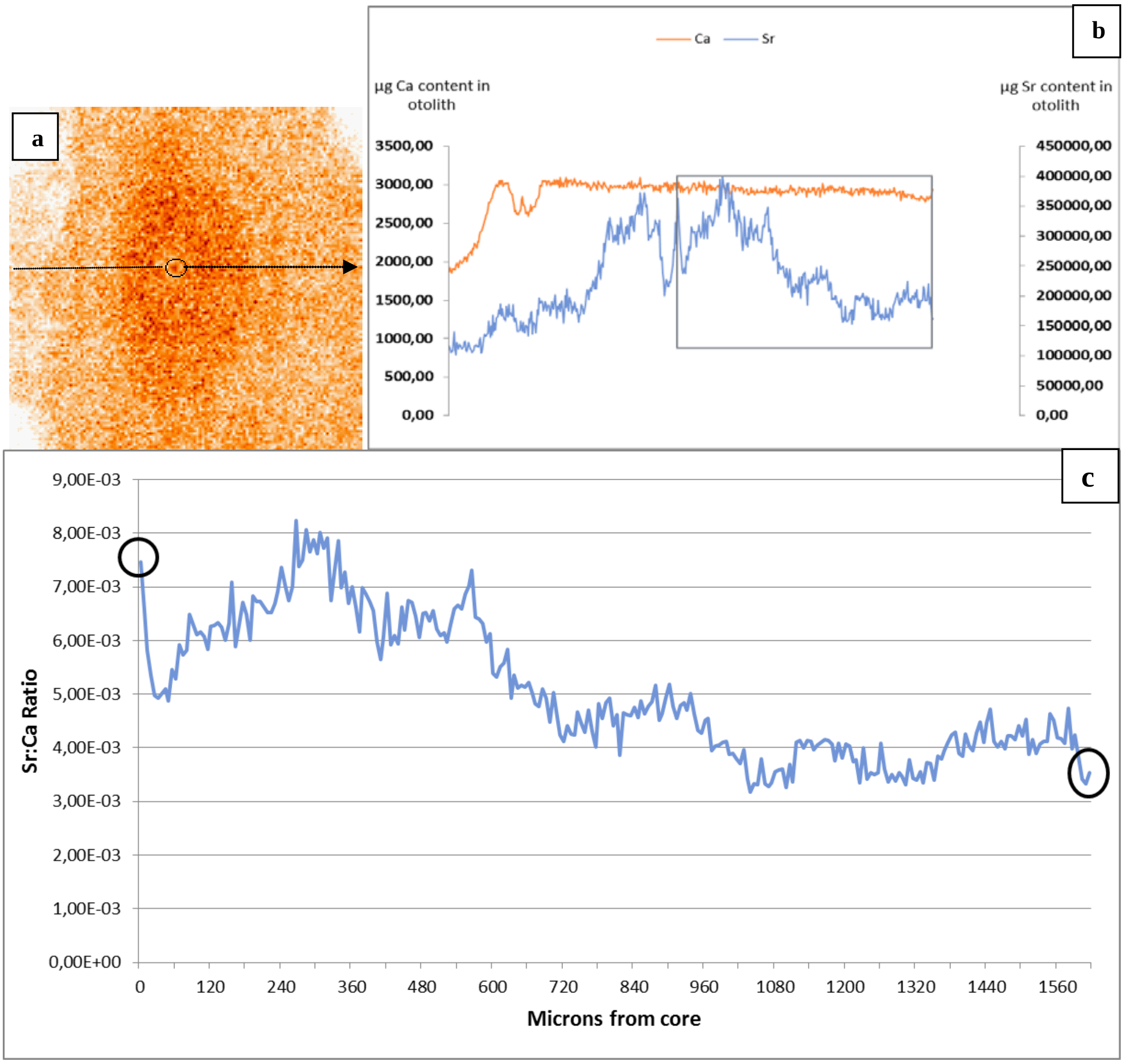

Fig. 4: (a) µPIXE scan image of an otolith from Holmön with the core identified in the centre, and likely transect path of the proton beam shown by the arrow. (b) Concentrations of Ca and Sr along the entire 512 point transect (a graphical replicate of the µPIXE scan). The black square indicates the most stable and informative portion of the otolith for analysis, from the core in the centre, to the edge on the right hand side. (c) The final Sr:Ca line plot: Black rings indicate the Sr:Ca ratios found at birth - otolith core (left) and progressively moving along the otolith until the outer edge is reached (right).

Figure 4b shows that the first part of the Ca line plot is unstable, and this is further illustrated by the white patchy areas on the left hand side of the image scan. Likely causes are that the otolith is very thin due to the most recent growth, or there was perhaps a preparation fault. In this otolith, information from the portion to the right hand side shown in figure 4b is most appropriate to extract. This critical analysis procedure was performed on every otolith profile to improve data quality.

The final product created was a Sr:Ca line plot (fig. 4c) which shows the changes in Sr:Ca concentrations throughout the life history of a particular fish. Data in this format makes the analysis and results comparable to other otolith chemistry studies and allows for assessment in any changes/trends over time from different areas in the Baltic Sea.

Establishment of a freshwater baseline:

A fundamental part of the study was to establish a baseline value to represent freshwater residency of perch. The baseline value was in the form of a Sr:Ca ratio and to achieve this, the 28 perch otoliths from the river Sävarån, Umeå were used as reference fish.

First, the part of the otolith in which a freshwater signal was most likely to be detected needed to be indentified. This should be at the start of the profile (close to the otolith core region) if it was to represent the birth environment in each respective fish. Profiles of all 28 fish were studied, and the point at which the lowest Sr:Ca value occurred was recorded. This indicated where in the otolith (µm from core) the strongest freshwater signal was most commonly found and will be referred to hereon in as the 'First Life Period' (FLP).

The actual Sr:Ca threshold indicating freshwater residency was established by calculating the mean Sr:Ca ratio at each interval point (every 6 µm) within the FLP, using all 28 fish. Then a 95 % confidence interval was calculated from these mean values, and the highest value from the 95 % confidence interval was used to represent the threshold value for freshwater residency.

To cross check the validity of this estimate, Sr:Ca values from the lake perch were included in the analysis. Since the lakes were dispersed geographically across Sweden, an estimate of the potential range of ambient freshwater values was obtained. The mean and maximium Sr:Ca values found within the FLP of each lake fish was assessed, and then overall 'lake means' calculated for each lake. A linear regression analysis was performed to assess whether geographic location (latitude) and respective Sr:Ca values in the lakes were correlated.

Origin of the coastal fish:

To determine the origin of the coastal fish, a similar procedure assessing the Sr:Ca values in the FLP was performed. Freshwater residency was confirmed if the minimum Sr:Ca value in the FLP of the fish was equal to, or less than the freshwater baseline value established from the reference fish.

Similarly, a fish was categorised as being of brackish (coastal) origin if the minimum value within the FLP was higher than the freshwater baseline value. The presence of a freshwater signal was recorded if found, and then the share of freshwater and brackish recruits determined for each coastal area. A one-way ANOVA test was performed to assess whether there was any significant difference in freshwater recruitment across the different coastal areas.

Indication of abrupt changes in environments between mother and offspring:

When a young perch emerges from the egg and develops in an environment with much lower salinity than its mother's resident environment, there is often a quite apparent 'dip' (generally within the first 0-100 microns) in the Sr:Ca profile (fig. 5).

A maternal signal (coding higher salinity) may hence remain in the otolith core region during very early egg or larval development, and is generally referred to as the 'mother peak'. The extent of the mother peak can vary but is often correlated to adult migration duration or distance (Miller et al, 2010).

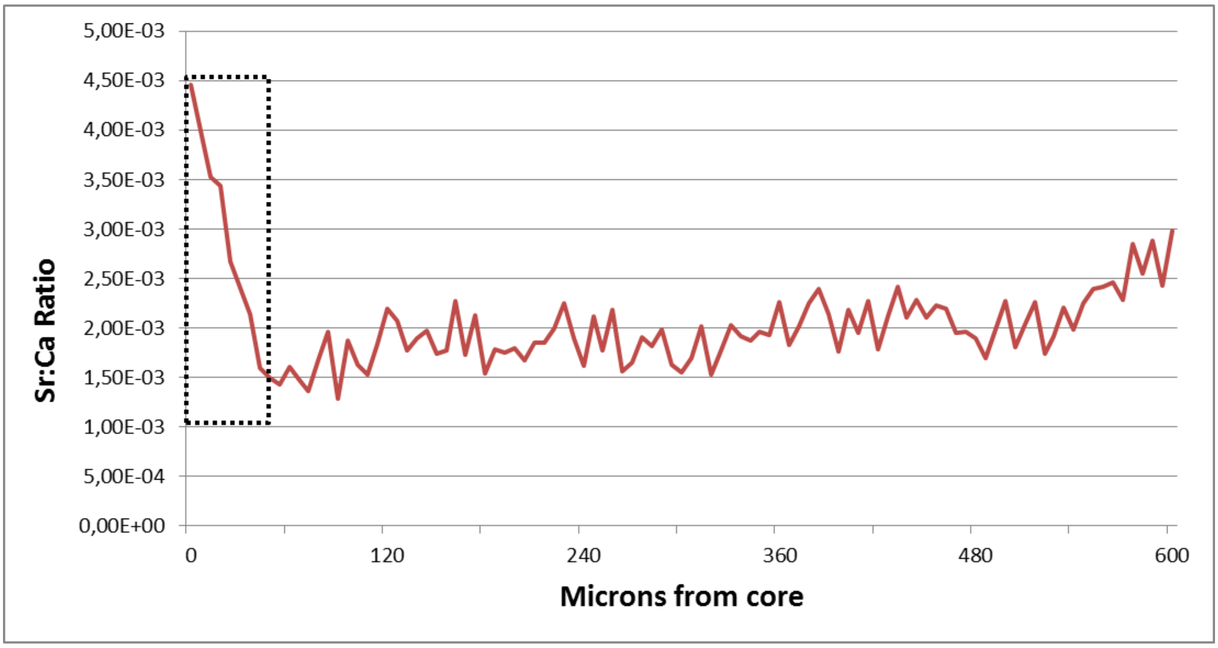

Fig. 5: Displaying a mother peak followed by an apparent 'dip' (shown within the dotted region) found in a fish from the river Sävarån. Many coastal fish in the study displayed a similar Sr:Ca profile.

The presence of a 'dip' from mother peaks was an additional means of speculating environmental preferences or migrations taken during the spawning period. Did female perch seek waters of higher or lower salinity than their normal, resident environment?

The lowest value in the FLP was recorded and then subtracted from the core value to display a 'dip value'. Based on the mean dip value from all fish, a 'dip' of $\geq 2.00 \times 10^{-3}$ was deemed to represent a notable change in salinity conditions, and hence referred to as a 'pronounced dip' (see fig. 12). The number of fish with a 'pronounced dip' was then counted and a percentage share of fish with 'pronounced dips' from the different coastal areas was determined.

Inverse dips, where the lowest value in the FLP was higher than the core value were also noted and significant differences regarding the variation in 'pronounced dips' at each coastal area was assessed using a one-way ANOVA test.

Relationship between otolith Sr:Ca values and ambient salinity levels:

As a final comparison, coastal salinities and their relationship to otolith core values in the coastal fish was assessed. Coastal salinities are highest at Torhamn in the south, and lowest at Holmön in the north of the Baltic Sea (table 2). If the ambient salinity in the coastal area is also mirrored in the otolith of a fish, then a relationship between salinity and the mean Sr:Ca value in the otolith core is expected. A regression analysis was performed to assess if there was in fact any correlation of these two parameters.

RESULTS

Establishment of a freshwater baseline:

Based on the Sävarån fish, the FLP was estimated to be found within a distance of 36-240 µm from the otolith core.This range was derived from findings which showed that in 26 of the 28 fish (93%), the lowest Sr:Ca ratio was found between 36-240µm from the otolith core. The two outliers which did not fall within this range had their lowest Sr:Ca ratios at 312 and 630 µm respectively from the core.

The mean Sr:Ca value in the FLP from an average fish at Säverån was $1.85 \times 10^{-3} \pm 1.32 \times 10^{-4}$ (Stdev) and the highest value of the 95% confidence interval of the mean values at each transect point within the FLP was 2.34×10^{-3} (fig.6). Therefore any specimens containing a Sr:Ca ratio within the FLP $\leq 2.34 \times 10^{-3}$ were assumed to be of freshwater origin.

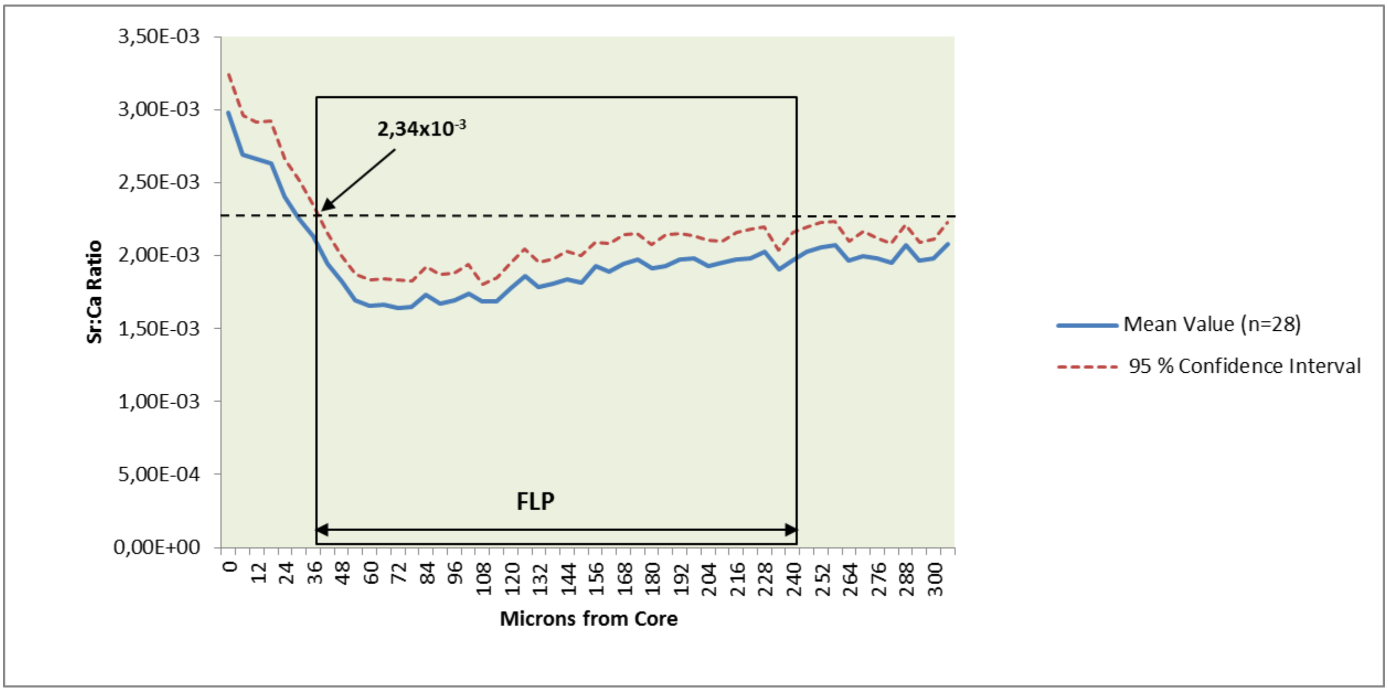

Fig. 6: The Sr:Ca ratio within the FLP of the reference fish from Sävarån. In blue are the mean Sr:Ca values from all 28 fish at each transect point in the FLP, and in red the 95% confidence interval of these means. The black dotted line shows the highest Sr:Ca value for freshwater from the River Säverån.

Lake Perch:

The Sr:Ca profiles in the lake perch otoliths showed that the highest Sr:Ca values within FLP varied across lakes, as did the mean values (table 3).

Table 3: Sr:Ca ratios found in the FLP at the six freshwater lakes, arranged geographically from north to south.

LAKE NAME	MAX SR:CA VALUE IN FLP	MEAN SR:CA VALUE IN FLP
Kånkåstjärnen	9.28×10^{-4}	7.95×10^{-4}
Motjärn	6.52×10^{-4}	6.50×10^{-4}
Geten	1.87×10^{-3}	1.57×10^{-3}
Stengårdshultasjön	1.25×10^{-3}	1.10×10^{-3}
Gyltigesjön	1.78×10^{-3}	1.35×10^{-3}
Stora Skärsjön	2.99×10^{-3}	2.27×10^{-3}

In one lake, Stora Skärsjön, some fish showed values in the FLP that were actually higher than the freshwater baseline estimated from the Säverån fish (fig.7). The results showed five out of 21 fish had Sr:Ca values in the FLP > 2.34×10^{-3} with the highest value at 2.99×10^{-3}. The other fish from this lake (16 out of 21) did however Sr:Ca values in the FLP that were below the freshwater baseline.
All fish from the other five lakes also had Sr:Ca ratios within the FLP < 2.34×10^{-3} and the highest value was 1.87×10^{-3} (table 3).

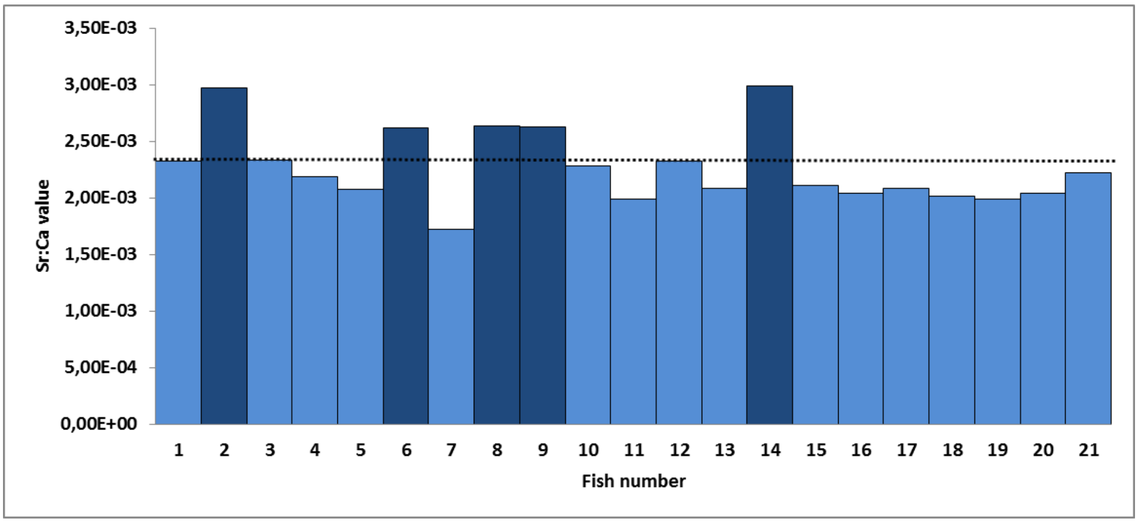

Fig. 7: The highest Sr:Ca ratios found in the FLP of the Stora Skärsjön fish, with the freshwater baseline value shown by the dotted line. Numbers 1-21 indicate each perch sample, light blue colouration showing fish with their highest FLP value <u>below</u> the 2.34 x 10^{-3} threshold, dark blue those fish <u>above</u> that vaule.

Sr:Ca values in the FLP appeared to decrease in lakes found in more northerly regions. A linear regression analysis showed how mean Sr:Ca values did generally decrease as the lake latitude increased to the north (fig 8). 41% of the variation in the mean Sr:Ca values in the FLP was explained by geographic latitude although the relationship was not significant (P=0.170).

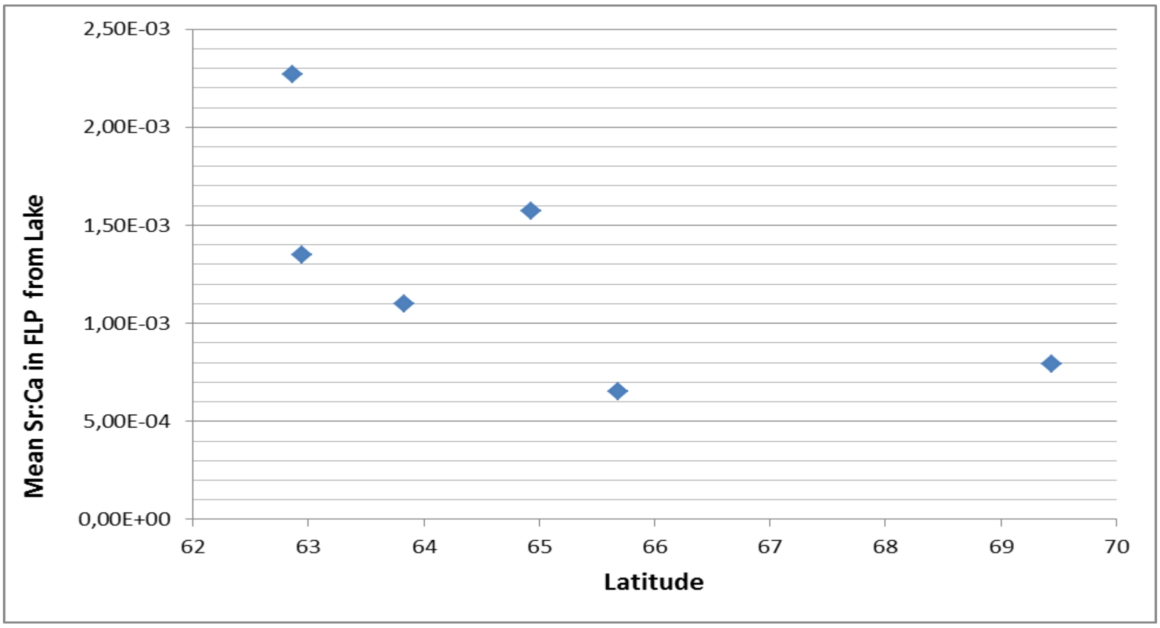

Fig. 8: Mean Sr:Ca values from the FLP at each lake were plotted and correlated to lake latitude.

Origin of the coastal fish:

In the majority of coastal areas, perch were mainly recruited in brackish waters (i.e the lowest Sr:Ca ratio in the FLP was above 2.34 x 10^{-3}). Such examples were found at Holmön, Långvindsfjärden, Kvädöfjärden and Torhamn (fig. 9). At one site (Gaviksfjärden), all fish appeared to be recruited in freshwater, and Forsmark comprised a mixture of both freshwater and coastal recruits. Differences in freshwater recruitment were highly significant across coastal areas (P= <0.001) and coastal area expained 72 % of the variation.

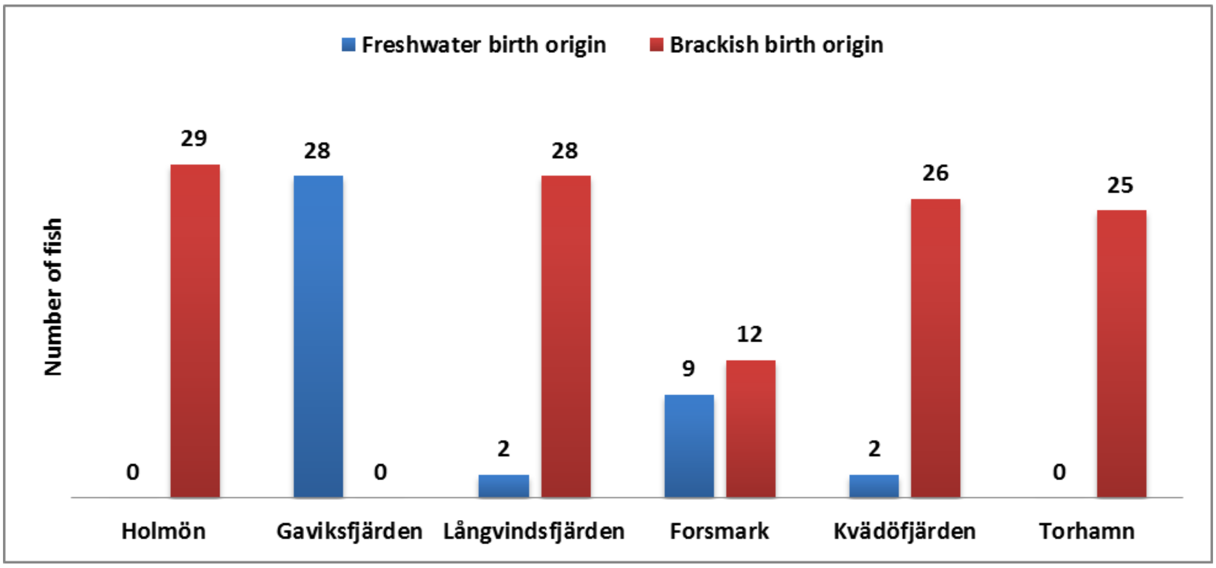

Fig. 9: The share of freshwater and brackish recruits in the six coastal sites based on a freshwater baseline of Sr:Ca ≤ 2.34 x 10^{-3}

The same analysis was done but using a freshwater baseline which was taken from the highest value found in the FLP from a perch at lake Stora Skärsjön (2.99 x 10^{-3}). This increased the share of freshwater recruits in two areas, Forsmark and Torhamn, but did not change the overall results (fig. 10).

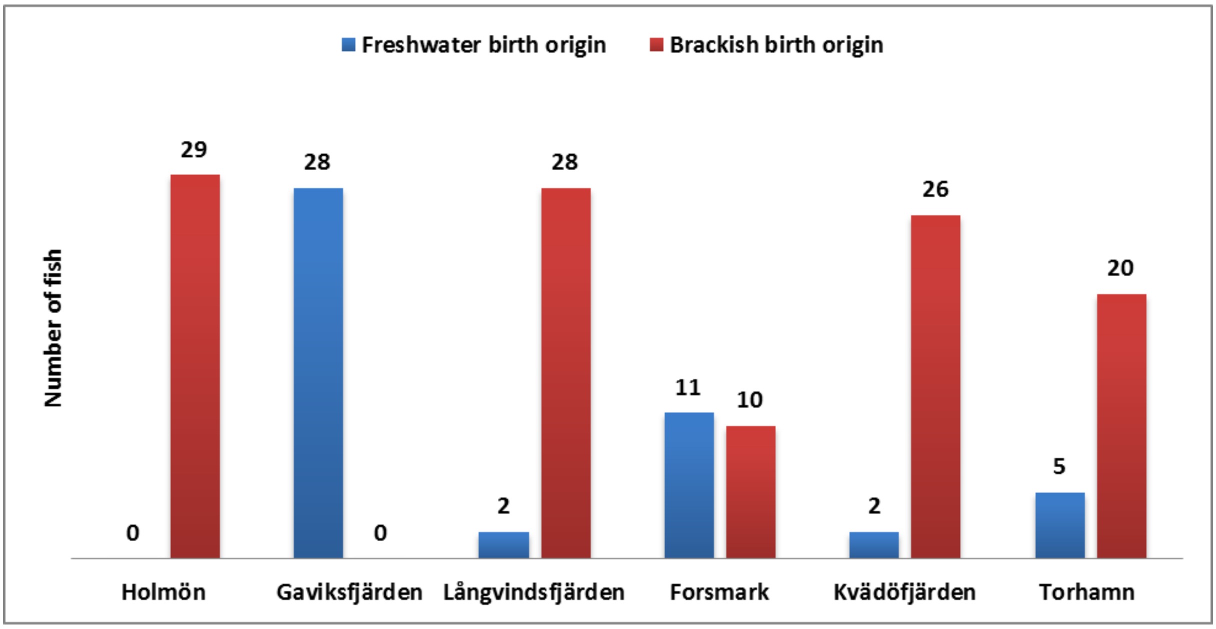

Fig. 10: A speculative change in the freshwater baseline was performed to see what difference it made to the results.

The Sr:Ca profiles of coastal perch born in freshwater and brackish waters are displayed for reference (fig. 11a and 11b).

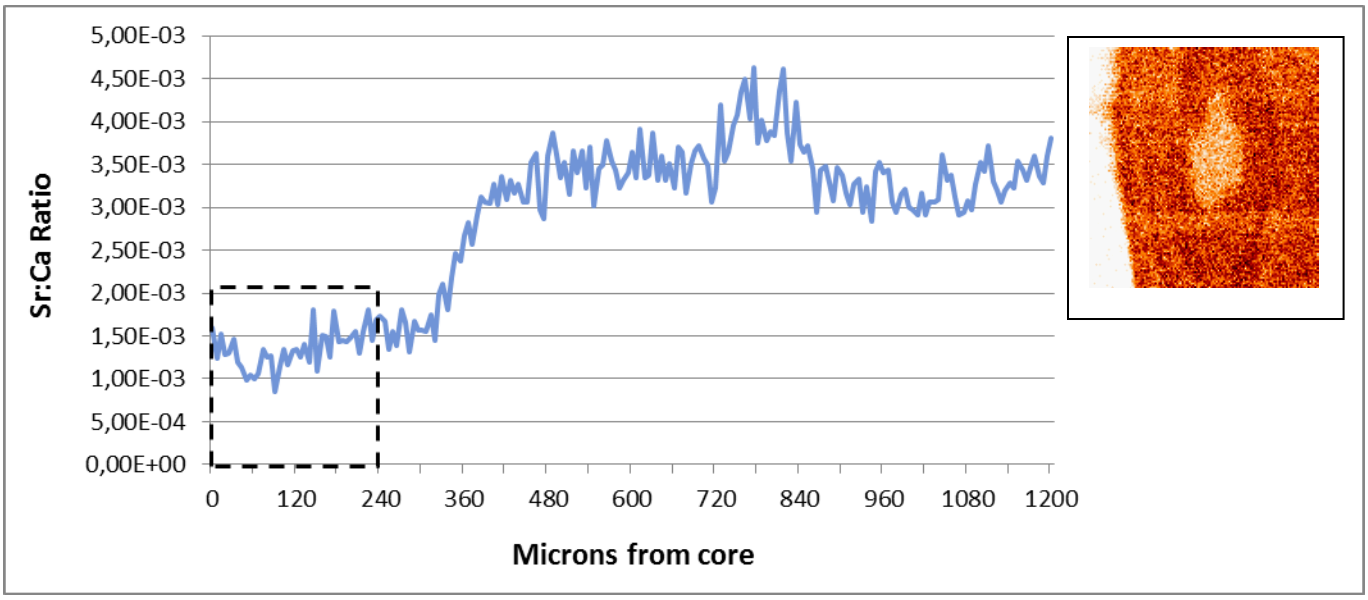

Fig. 11a: Sr:Ca profile of a freshwater recruited perch at Gaviksfjärden; FLP values $<2.34 \times 10^{-3}$ (boxed area). The scan image is also suggestive to birth origin, with lighter colouration in the core region (centre) indicating lower Sr concentrations.

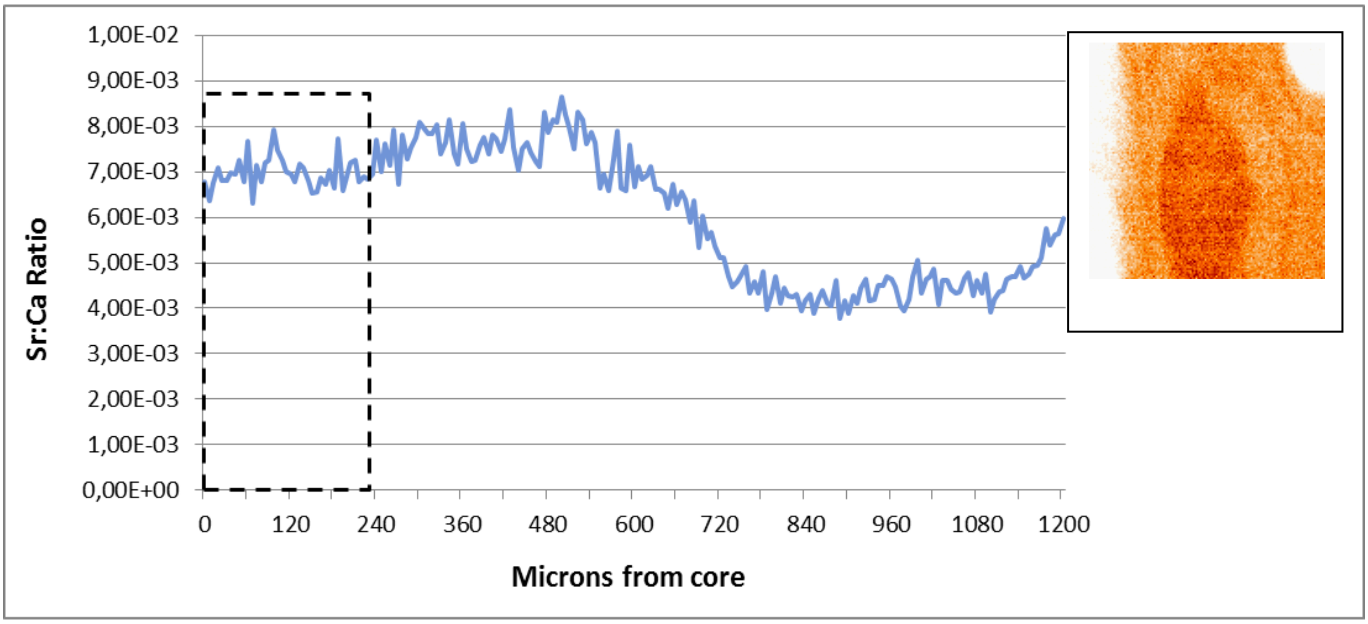

Fig. 11b: Sr:Ca profile of a brackish recruited perch from Holmön; FLP values $>2.34 \times 10^{-3}$ (boxed area). The image displays darker bandings within the core area where higher Sr concentrations are found, with lighter colourations seen as the fish migrates to waters of lower salinity later in life.

Indication of abrupt changes in the environment experienced by mother and offspring:

The distribution of ‘dip’ values from all 161 coastal fish was plotted (fig. 12). The mean Sr:Ca dip value was shown to be 1.51×10^{-3}. Based on this mean value, a fish with a dip value $\geq 2.00 \times 10^{-3}$ was therefore assumed to represent a significant or ‘pronounced dip’. Fish showing a negative dip value under zero were classed as having an ‘inverse dip’.

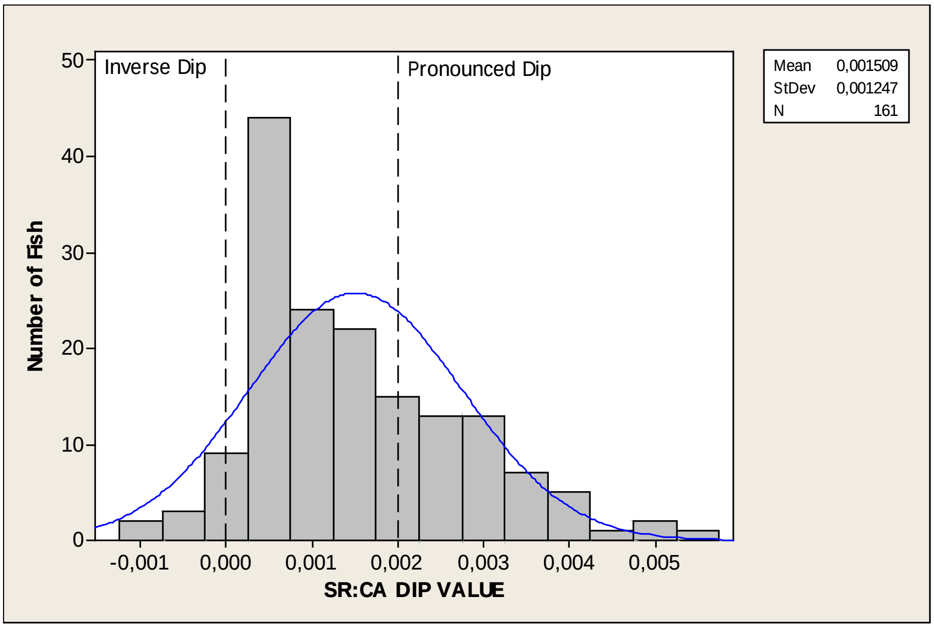

Fig. 12: Dip distribution values: The dotted lines show firstly where there is zero change in dip values (Sr:Ca = 0.000) and secondly where there was a notable or 'pronounced dip' (Sr:Ca=0.002).

The share of fish from each coastal area showing a 'pronounced dip' $\geq$ 2.00 x 10^{-3} was then calculated and was shown to vary across the different coastal sites (fig. 13).

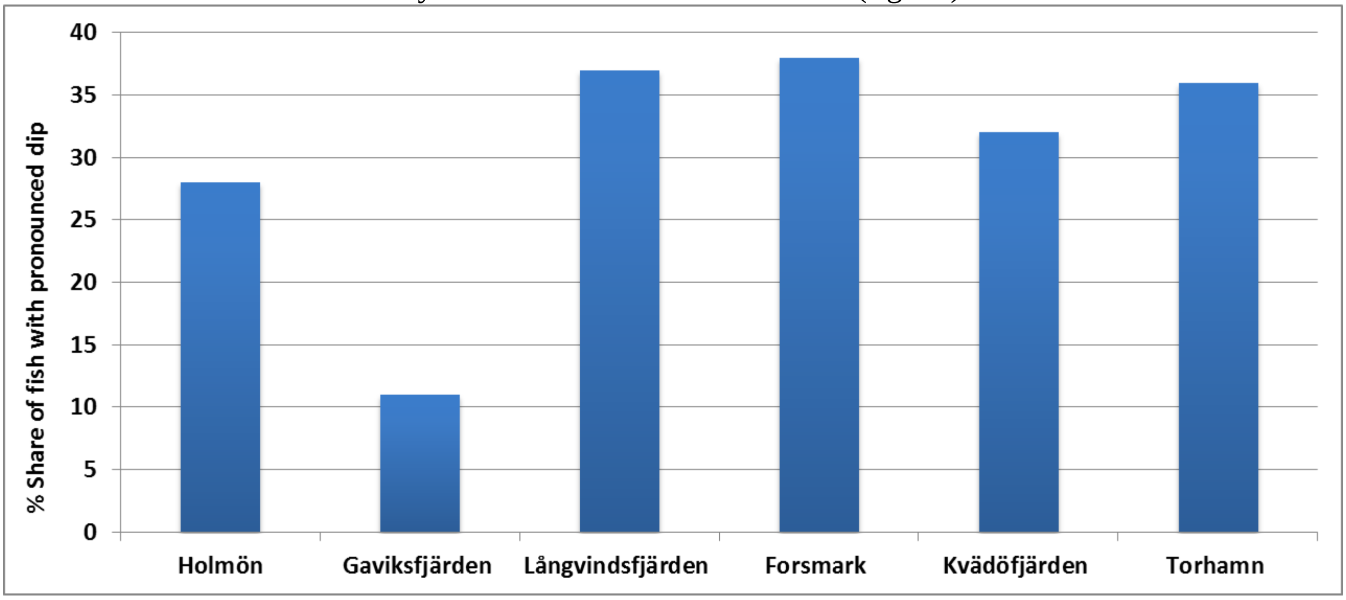

Fig. 13: The share of fish with pronounced dips across different areas - Holmön 28 %, Gaviksfjärden 11 %, Långvindsfjärden 37 %, Forsmark 38 %, Kvädöfjärden 32 %, and Torhamn 36 %.

In total, 48 fish out of 161 (29.8 %) had a pronounced dip. If Gaviksfjärden is discounted then the share of fish with pronounced dips was in fact rather even across areas (between 28-38 %) occurring most frequently at Forsmark, Långvindsfjärden and Torhamn.
Six fish of the 161 had an inverse dip where the lowest value in the FLP was higher than the core value (five fish at Holmön, and one at Långvindsfjärden) suggesting the juvenile fish were born in environments with higher ambient salinities than the respective mother fish.

Dip values from each fish at each coastal site were combined to form a 'mean dip value' which showed a more generalised picture from each area (fig. 14). This provided scope for further specualtion about the maternal spawning preferences, or the likelihood for migratory journeys in that coastal area.

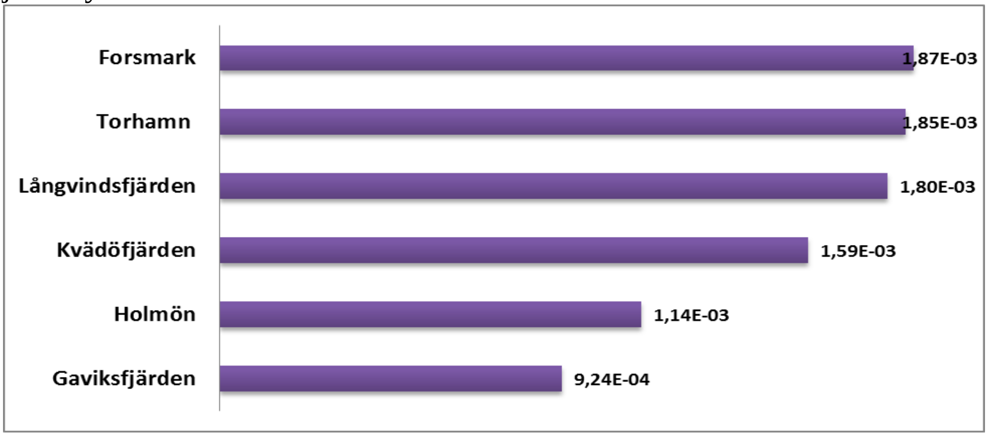

Fig. 14: Showing 'Mean dip values' at each coastal site

The mean Sr:Ca dip value found at Forsmark was greatest (1.87×10^{-3}) compared to fish at Gaviksfjärden which showed the smallest mean dip variation (0.92×10^{-3}). A one-way ANOVA test showed there was a statistically significant variation in 'dip values'across the different coastal areas (P=0.013).

Relationship between otolith Sr:Ca values and ambient salinity levels

There were substantial differences across coastal areas in the mean Sr:Ca core values of the fish (fig. 15). There was, however, no correlation associated with ambient salinity and mean Sr:Ca values (R^2 =0.0009; P=0.969) which was unexpected given the large salinity gradient across the different coastal areas (i.e from Holmön 3.5 ‰ to Torhamn 6.9 ‰).

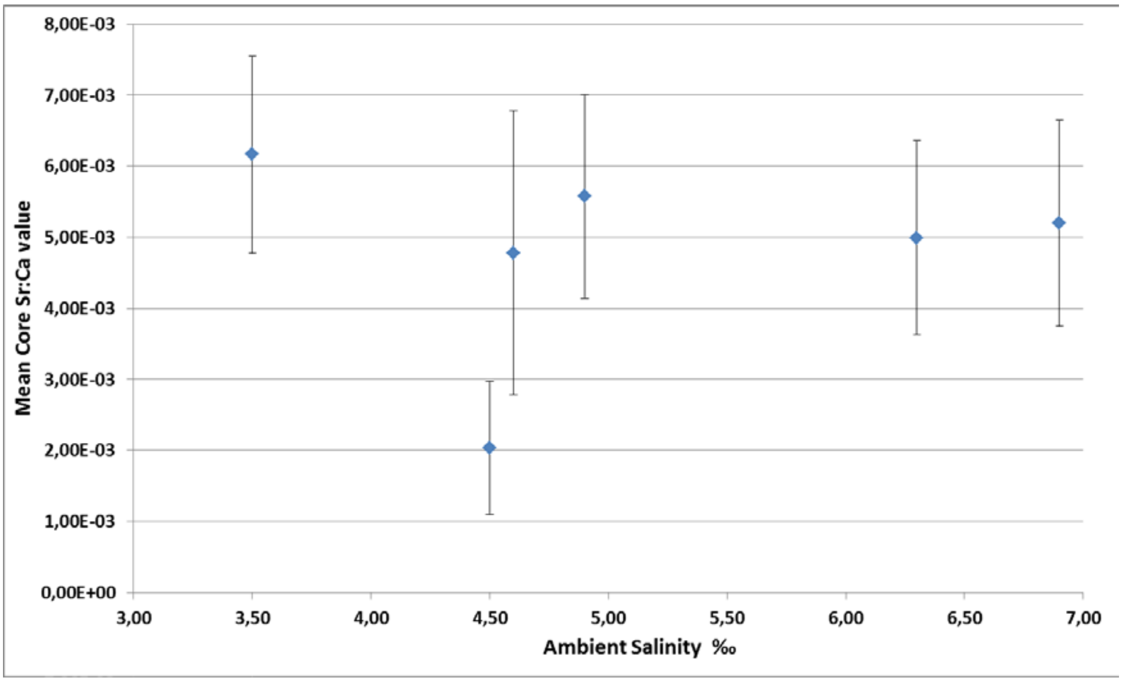

Fig. 15: Showing the relationship between ambient water salinity and mean core values found at the different coastal sites.

DISCUSSION AND CONCLUSIONS

In some coastal areas, freshwater habitats appear to be important for the recruitment of pike in the Baltic Sea (Lehonen and Hudd, 1990; Westin and Limburg, 2002; Engstedt et al, 2012), but little research has been devoted to assessing this issue for resident coastal perch. In this study I first established a Sr:Ca baseline value indicating freshwater residency in perch, and then assessed the share of freshwater recruited perch from six coastal areas along the Swedish Baltic Sea east coast. The results suggested that freshwater systems are generally not of high significance for perch recruitment in coastal areas, but there is substantial variation across areas. In one area, Gaviksfjärden, all analysed perch specimens were recruited in freshwater.

Freshwater baseline:

The basis for calculating exactly where to search for the freshwater signal within the otolith was assumed to be fairly trustworthy; 26 out of 28 fish from the river Sävarån displayed the lowest Sr:Ca signal within a similar range from the otolith core. The two fish that did not fall within this range may have been several weeks/months old when their lowest Sr:Ca signals were detected and hence were not included in the baseline determination as they could have migrated away from their respective birth environment.

When cross-checking the freshwater baseline from the Sävarån fish, and Sr:Ca values found in the lake fish, it seemed like the baseline estimate was reasonable. I considered that the baseline could be set marginally lower since the FLP values from perch in five out of six lakes were all below the threshold. However the higher values from the five individuals in lake Stora Skärsjön meant that the baseline value was not set lower. The highest of these values was 2.99×10^{-3} but suggestions that this value was perhaps too high to be truly representative of freshwater origin were (i) the mean core value for this lake was only 1.90×10^{-3} showing that the majority of resident mother fish did not contain such high strontium levels, and, (ii) the average maximum FLP value from all 21 fish was only 2.27×10^{-3} showing a more generalised picture from the lake. Previous otolith chemistry studies from Baltic Sea coastal areas also suggested a freshwater baseline of around 2.00×10^{-3} in perch (Lozys et al., unpublished) and around 2.50×10^{-3} or under in pike (Westin och Limburg 2002; Rohtla et al., 2012). Whilst there is an inter-species difference regarding the uptake of strontium into fish otoliths (Lill et al., 2013), these studies suggested that the Sävarån freshwater estimate for perch was not unrealistic.

Bedrock geology was considered as a possible factor as to why some perch otoliths in lake Stora Skärsjön had slightly higher Sr:Ca values than otoliths from the other lakes, or Sävarån. However, since all lakes were located in areas with granitic bedrock, a potentially higher dissolved Sr content in the lake was not deemed a bias factor. Notably, it was only five fish which had higher Sr:Ca values - not every specimen from the lake. Therefore it is likely that other more specific factors such as diet, water temperature or preparation/analysis faults could be held responsible.

Freshwater recruitment of the coastal fish:

Freshwater spawning may bring certain benefits for perch, since the temperature in shallow spawning areas such as streams or wetlands rises quickly in the spring, and stimulates earlier hatching of perch fry (Engstedt et al., 2012). An earlier start in life could be advantageous for perch fry since they can grow quicker making them superior competitors for common resources such as food, as well as reducing their risk of predation.

The Baltic Sea coastal environment is also where more fish species such as older perch, pike, sticklebacks and roach are often present (Nilsson, 2006), therefore posing a potentially higher predation risk to larval and juvenile perch. In addition, it appears that perch have a lower tolerance to brackish water in the younger life stages, and a migratory life strategy to

freshwater systems for breeding purposes can lead to higher growth rates, often improving survival rates in the young perch fry and larvae <90 days old (Tibblin et al., 2011).
Despite productivity normally being higher in the sea (Gross et al., 1988), decisions made by a female perch to migrate to freshwater systems for spawning or not are likely to be based upon the actual availability of food or the relative risk for predation (Olsson et al, 2006). Many fish species seem to exploit temporal pulses in food availability, or avoid predation by spawning in habitats that provide shelter during certain times of the season (Urho, 2002). Therefore specific biological conditions or fish community composition at each coastal site could be an influential factor favouring freshwater spawning.

It also appears that the proportion of freshwater systems in relation to brackish water sites is naturally of high relevance for the recruitment share of freshwater perch in coastal areas, especially since perch are relatively stationary and the longest typical adult migration distance is around 10 km (Saulamo and Neuman, 2002). Holmön for example has little or no suitable freshwater sites and all the fish were brackish recruits. The mean Sr:Ca value in the FLP at Holmön was also higher than all other areas suggesting that these fish were subject to very limited, or no freshwater influences. The lowest Sr:Ca value in the FLP profiles of the Holmön fish was also well above the freshwater baseline, which is not particularly surprising given the fact the island location is somewhat isolated out in the open sea, 10 km from the mainland.
At Torhamn, all recruits were also born in brackish water, but similar to Holmön, the geography of this site renders it liable to brackish water reproduction. There is only one obvious freshwater input, that being a small canal to the north of the site. Having said that, it would appear that the coastal recruitment areas are somewhat influenced by freshwater as five fish had their lowest Sr:Ca values in the FLP close to the freshwater baseline, and the majority of Sr:Ca values in the otolith cores were not exceptionally high either. Factors such as surface run-off from nearby urbanised areas, throughflow drainage of agricultural land, or smaller discrete freshwater outlets could be potential contibutors of freshwater creating the dilusion of brackish water in the reproductive areas.

At Långvindsfjärden and Kvädöfjärden, there are accessible freshwater systems present for spawning, however brackish water habitats greatly outnumber the freshwater alternatives. This could be a plausible explanation for the low number of freshwater recruits in these coastal areas. Furthermore, the abundance of small islands and rocky outcrops at both of these sites appears to offer suitable, sheltered spawning habitats which are utilised to a much greater extent. It seems that many adult fish reside in the outer archipelago in these two coastal areas (bearing higher salinity) and then migrate in closer to land areas for reproduction in suitable brackish water sites. This could be supposed since mean Sr:Ca values in the otolith cores were high, and many juvenile fish had pronounced dips from these areas.
At Kvädöfjärden two freshwater recruits were found, but the mother fish of these recruits had likely been residing in freshwater prior to spawning (perhaps for over-wintering) since the Sr:Ca core values of these two fish were already low.

Gaviksfjärden and Forsmark have somewhat more developed freshwater networks, and a higher number of freshwater recruits were found in these areas. All 28 perch at Gaviksfjärden were recruited in freshwater - a unique finding.

Although there is a large number of freshwater recruitment habitats available at Gaviksfjärden, it is also likely that predation pressure during early life stages, or competiton for food resources from the vast abundances of three-spined sticklebacks could be highly influential on the survival of juvenile perch. It may be that the impact of the sticklebacks is so severe that all coastal perch recruits are either predated or outcompeted, and the only survivors in the coastal area are those recruited in freshwater habitats where sticklebacks have restricted access. This theory could also explain why population densities of perch have remained relatively stable between 2004-12 (Lingman, 2013), should specific freshwater recruitment sites continually prove successful in rearing a similar number of juvenile perch across years. Indeed previous studies at Gaviksfjärden have already noted the importance of two key freshwater sites for perch reproduction (Byström, unpublished data).

The 2007 birth year also produced a far stronger year class than average at Gaviksfjärden (Lingman, 2013), which may further demonstrate the reproductive benefits of freshwater recruitment, although successful year classes in many cases are dependent on a warm water temperatures during the first growth period between June and August (Lingman, 2013).

Coastal gill netting at Gaviksfjärden (2004-2009) revealed that this coastal area represents lower perch CPUE compared to any of the other coastal sites in the study (HELCOM, 2012) which further implies the crucial importance of recruitment sites in maintaining the proportionally low predatory perch numbers.

At Forsmark a number of freshwater recruitment sites are available and a mixture of both freshwater and brackish recruits were found. There was also a large varitation in Sr:Ca core values which strongly suggests that adult fish have been residing in waters with varied salinites prior to spawning.

Previous otolith chemistry analysis in perch at Forsmark has been conducted on eight different occasions between 1994-2009, and these results show annual variations with regards to the share of fish being recruited in fresh or brackish water (Olsson, unpublished data). In 2007, there was more freshwater recruitment (43 % of fish) than in any other year within the time series, and in general freshwater recruitment is very low; only 11 fish from 137 analysed (8 %) were freshwater recruits.

This may be related to the fact that 40 % of the coastal monitoring area in Forsmark is <3m deep, with large areas highly sheltered from wave exposure by numerous small islands and rocky outcrops. Thus suitable brackish water spawning grounds appear to be more numerous and adequate for spawning than the nearby freshwater alternatives. Why 2007 was such an exeptional year is unclear but could be related to localised changes in fish community composition, lower food availability or less favourable water conditions in the brackish areas prior to spawning. Environmental influences at the site of egg incubation can have severe impacts on the survival off fish eggs (Sandström et al., 1997), so it could be assumed that female perch select the most favourable spawning sites based on specific water conditions each year.

Migration to waters with different salinty :

The '% share of fish with a pronounced dip' was presented instead of the 'number of fish with a pronounced dip' because there were small differences in the actual number of fish analysed from each coastal area. This study showed that on average 30 % of juvenile fish caught in coastal areas had a 'pronounced dip' in their Sr:Ca profiles suggesting that perch movement into waters with notably lower salinity for spawning is not uncommon in the Baltic Sea. This could be attributed to the fact that perch often migrate to shallower and warmer shoreline areas prior to spawning in order to find sheltered estuaries, lagoons and bays which are important nursery areas (Snickars et., al 2010; Sundblad et al., 2011). These shallow sites may also contain macrophytes, cobbles and stones, submersed woody debris or anthropogenic structures on which egg strands can be attached (Winfield, 2004), and can also offer refuge from predation for the newly hatched fish. Indeed sheltered sites closer to the shoreline are naturally more influenced by freshwater and hence they often contain lower salinity resulting in the ‘pronounced dips’ in many of the juvenile perch Sr:Ca profiles. This migratory behaviour was most commonly displayed at Forsmark, Långvindsfjärden, Kvädöfjärden and Torhamn.

The recruitment of perch in exposed outer archipelago areas is also restricted as the water temperature is too cold (Karås, 1996) or subject to hydrodynamic stress caused by wave-generated currents which can damage eggs directly, or dislodge attached eggs to less favourable locations (Probst et al., 2009). Forsmark is a good example of this as many areas of the site are somewhat exposed to the open sea. The ‘mean dip value’, as well as the share of fish with ‘pronounced dips’ was higher at this site than any other, indicating that on average mother fish had undertaken the furthest migratory journeys (or experienced the sharpest change in salinity over shorter distances), in order to find optimal spawning grounds.

Dip values at Holmön suggest that mother fish are more likely to spawn close to their resident environments, or atleast in environments with similar salinity, since the mean dip value was fairly low at this site. It could also be that there is no sharp salinity gradient between the mother’s resident habitat and spawning site. Five individuals at Holmön also had inverse dips, which shows that mother fish have opted to spawn in sites with a higher salinity than their own resident environment. This could be linked to the site geography which is quite exposed to the open sea, and fish have little option but to spawn in brackish water which may inevitably be of higher salinity than their resident habitat.

With regards to water salinities in the Baltic Sea, a gradient is formed as freshwater from several large rivers enters the Sea in the north, and more saline water arrives from Öresund and the Belts in the south. In this study however, there was no correlation linking Sr:Ca ratios in the otolith cores and geographic location. Salinity is generally regarded to be the main component influencing Sr uptake in otoliths, but another elemental uptake pathway is from food. Variations in diet at the different sites could therefore be influential to some extent. Engstedt et al., (2012) suggested that food significantly affects Sr concentrations in pike otoliths from the Baltic Sea, and similarly, Buckel et al., (2004) noted that restricting the diet of bluefish (*Pomatomus saltatrix*) to exclusively shrimp or fish, resulted in a significantly higher Sr otolith content in the shrimp fed group.

When establishing the freshwater residency baseline it may have been useful to analyse perch otoliths from other river systems in more southerly areas as well. Since there were some differences in Sr:Ca values of the lake fish, to some extent dependent on the location of the lake, and this may therefore also to be true of freshwater recruited coastal fish. Thus an inclusion of additional reference fish would allow spatial comparisons to be drawn from different river systems. If a higher freshwater baseline should be detected from other river systems, then the representative share of freshwater recruits may increase in some of the coastal areas, potentially altering the overall significance of freshwater systems. The Torhamn results in particular could be affected by this, since several fish had their lowest Sr:Ca values (in the FLP) fairly close to the border separating fresh and brackish water.

Urho (1996) noted the abundance of larval perch in the pelagic zone of a Finnish lake just days after hatching in the littoral zone, with many larvae still bearing the yolk sac. This shift to pelagic areas in larval perch was also noted by Treasurer (1988), and Wang and Eckman (1994) and illustrates the tendency of larval fish to migrate almost immediately after hatching. Should this behaviour be exhibited in river systems then currents may translocate the young fry downstream to coastal areas before the freshwater signal in the otolith could even be detected, resulting in a higher representation of brackish recruits that were in fact born in freshwater.

Further causes of inaccuracy or misclassification in the study may have arisen from dirt or other foreign particles on the otolith surface prior to μPIXE analysis. Cracks in the otolith caused during preparation may have also affected chemical detection accuracy.

The importance of freshwater systems for the recruitment of perch into Baltic Sea coastal ecosystems:

In some Baltic Sea coastal areas, freshwater habitats seem to be very important for the recruitment of coastal fish populations, and protection and restoration of these habitats may be of paramount importance.

On the whole however, it seems that the most important habitats to protect are those in the coastal areas. The pressure on many organisms inhabiting coastal areas is often severe, a result of the high concentration of human activities (Airoldi and Beck, 2007). For coastal perch, important recruitment areas are often found in shallow sheltered bays. These sites are also popular for boating or recreational housing (Sandström, 2005) and therefore in future management plans, the habitat protection of coastal spawning grounds should be advocated.

With perch populations currently decreasing at Långvindsfjärden, Forsmark and Kvädöfjärden a key strategy must be to identify the important recruitment sites and employ land or water management strategies in order to restore the predatory populations into the Baltic Sea. If these measures are in place there is a better chance of returning coastal ecosystems to a natural state, and in doing so preserve those social and economical values which perch bring to us as humans.

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Information and details regarding the lake perch was obtained from Magnus Kokkin at the SLU Department of Aquatic Resources, Freshwater Laboratory, Drottningholm, Stockholm.

Perch specimens collected from the river Sävarån, and details relating to perch spawning sites at Gaviksfjärden were obtained via Pär Byström, Umeå University.

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